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Effect of El Niño southern oscillation on the ozone concentration of Indian cities

Nandita D Ganguly[1]* and K N Iyer[2]

[1]Department of Physics, St. Xavier's College, Ahmedabad-380 009, Gujarat, India

[2]Department of Physics, Saurashtra University, Rajkot-360 005, Gujarat, India

E-mail : nanditad@icenet net

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Abstract : The effect of El Niño southern oscillation (ENSO) on the Total, Tropospheric and Stratospheric ozone concentration from 1980 to 2003 at Kanyakumari (8°N, 77.6°E), Rajkot (22.3°N, 70.8°E), Delhi (28.5°N, 77.3°E) and Srinagar (34°N, 75°E) has been studied using the data obtained from total Ozone Mapping Spectrometer (TOMS) and Tropospheric Ozone Residual method (TOR). The effect of ENSO on the seasonal variation of Total ozone at these four stations has been investigated The observed results and possible causes for the breakdown in ozone-ENSO relations in certain years, have also been discussed in the paper.

Keywords : El Niño southern oscillation (ENSO), tropics, ozone concentration, southern oscillation index (SOI), multivariate ENSO index (MEI).

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1. Introduction

The El Niño current arises, as the ocean and atmosphere interact, to balance Earth's thermal energy. A large scale weakening of the trade winds and warming of the surface layers in the eastern and central equatorial Pacific Ocean, characterizes El Niño. Normally, the waters of the eastern Pacific Ocean near South America are quite cool as a result of upwelling ocean currents. The tropospheric trade winds normally traverse from east to west in this region. However, in an El Niño period, the trade winds weaken, allowing the warmer waters of western Pacific to migrate eastwards. This change in temperature of the sea surface water causes large-scale shifts in the global circulation patterns in the Troposphere and lower Stratosphere which in turn, affects the transport of ozone in these regions. This oscillation is very irregular, with a period of 4 to 7 years between episodes. They typically last 12–18 months, and are accompanied by swings in the Southern Oscillation (SO), an interannual seesaw in tropical sea level pressure between the eastern and western hemispheres. The coupled oceanic-atmospheric character of ENSO can be explained with the help of the Multivariate ENSO Index (MEI), which is a weighted average of the main ENSO features contained in the following six variables : sea-level pressure, the east-west and north-south components of the surface wind, Sea Surface Temperature (SST), surface air temperature and total amount of cloudiness. When this index is negative, we have a La Niña (or ocean cooling), and when it is positive, we have an El Niño (or ocean warming).

Hasebe [1] studied the interannual variations of Total ozone (1970–1977) and found the oscillation with a period of about four years (FYO). When El Niño takes place, the Brewer-Dobson circulation enhances the ozone transport in the Stratosphere. Therefore, the Total ozone increases in the extra-tropics and decreases in the tropics [2]. Singh *et al* [3] studied the effect of El Niño on Total ozone column. They observed anomalous high values of Total column ozone around January-March 1998 at Delhi, Lhasa and Beijing, which was found to coincide with high SST increase over the equatorial Indian Ocean due to the strong El Niño effect. Chandra *et al* [4] observed that during an El Niño period, Total ozone column decreased by 4–8 DU in the eastern Pacific and increased by about 10–20 DU in the western Pacific.

*Corresponding Author

Although there is a general tendency to hold El Niño responsible for almost anything unusual that happens anywhere, relationships between El Niño and rainfall, floods and droughts are well established. The effect of El Niño on ozone is being studied globally, but it needs investigation by the scientific community in greater details. In view of these considerations, the effect of El Niño on the ozone concentration of Indian cities has been studied in this paper.

2. Data and analysis

The effect of El Niño on the Total ozone concentration at Kanyakumari (8°N, 77.6°E), Rajkot (22.3°N, 70.8°E), Delhi (28.5°N, 77.3°E) and Srinagar (34°N, 75°E) is studied using the data obtained from Total Ozone Mapping Spectrometer (TOMS). TOMS is a source of high-resolution global information about the Total ozone content of the atmosphere. It measures the ultraviolet sunlight back scattered from the clouds or the ground to measure the Total ozone amount. It cannot measure night-time ozone or make measurements in the winter polar darkness. The largest amount of satellite-based ozone measurements comes from the Solar Back Scattered Ultra Violet Technique (SBUV). In this method, the ratio of sunlight scattered back to the spacecraft from the earth-atmosphere system to that incident at the top of the atmosphere is used to determine the ozone amount. The Tropospheric ozone data obtained from the Tropospheric Ozone Residual (TOR) method for the years 1980–1998 for Kanyakumari, Rajkot, Delhi and Srinagar has been studied to determine the impact of El Niño on Tropospheric ozone. Fishman *et al* [5] at NASA Langley Research Center in Hampton developed the TOR method of deriving Tropospheric ozone from satellite measurements. The TOR was initially developed utilizing coincident observations of Total ozone from the TOMS instrument and Stratospheric ozone profiles from the Stratospheric Aerosol and Gas Experiment (SAGE) instrument. At present, the total column amount of ozone from the TOMS instrument is being used, but the Stratospheric ozone profiles from the SBUV instrument have replaced the profiles from SAGE. The change from the SAGE instrument to the SBUV instrument was made because of the much greater data density provided by the SBUV instrument. Gridded global values of Tropospheric column ozone are available between 50°N and 50°S with 1° latitude by 1.25° longitude horizontal resolution up to December 2000. The distributions are determined by subtracting the empirically corrected Stratospheric column ozone amount derived from the SBUV instrument from the total column ozone measurements made by TOMS.

3. Results and discussion

The effect of El Niño on the Total ozone concentration at Kanyakumari (8°N, 77.6°E), Rajkot (22.3°N, 70.8°E), Delhi (28.5°N, 77.3°E) and Srinagar (34°N, 75°E) is studied using the data obtained from Total Ozone Mapping Spectrometer (TOMS). An examination of the yearly mean values of Total ozone from 1980 to 2003 (Figure 1) indicates that the ozone concentration decreases in the

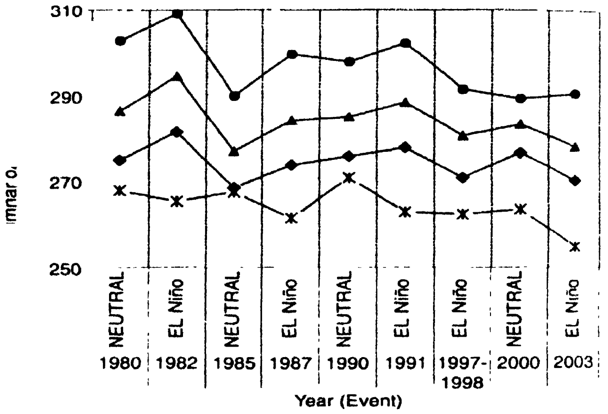

Figure 1. Effect of El Niño on Total ozone concentration.

tropics (Kanyakumari), and increases in the extra-tropics (Srinagar and Delhi) during an El Niño period. This is because, when El Niño takes place, the Brewer-Dobson circulation enhances ozone transport in the Stratosphere. Yamazaki and Yagai [2] observed similar results in their atmospheric general circulation model (MRI.GCM). The Total ozone concentration at Rajkot, situated close to the border of Tropical and extra-Tropical region, is found to be higher during an El Niño period compared to neutral period except in 1990 and 2000. This may be because the neutral years 1990 and 2000 also correspond to the solar maxima years of the 11 year solar cycle, which is associated with maximum sunspot activity (Figure 2). The UV output of the sun increases as sunspot activity increases which in turn, increases the production rate of Ozone [6].

An examination of the effects of El Niño on the Tropospheric ozone derived from Tropospheric ozone Residual method (TOR) at these four stations indicates that the Tropospheric ozone is higher at Srinagar, Delhi and Rajkot during an El Niño period compared to neutral

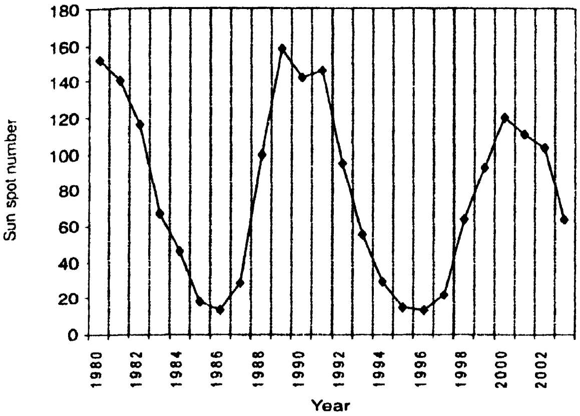

Figure 2. 11-Year solar cycle.

period except in 1990–1993 (Srinagar and Delhi) and 1989–1990 (Rajkot). This low value of observed ozone level may be because the El Niño period of 1990–1993 also witnessed a major volcanic eruption from Mount Pinatubo in Philippines in June 1991. After this eruption, ozone loss by different amounts was reported from different parts of the world in 1992–1993 [7]. No significant Tropospheric ozone trend is observed at Kanyakumari (Figure 3).

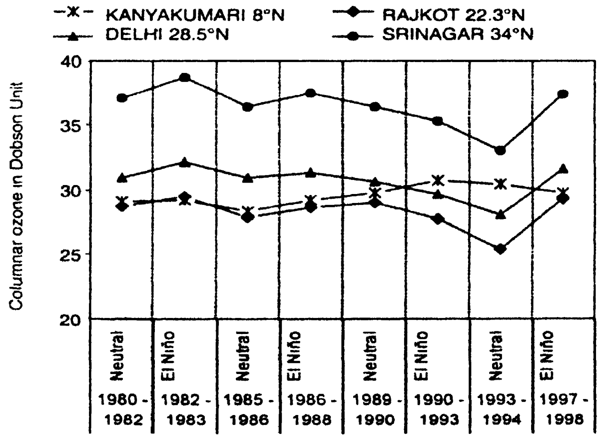

Figure 3. Effect of El Niño on Tropospheric ozone concentration.

The Tropospheric ozone values for these four stations obtained from TOR were subtracted from the Total ozone values obtained from TOMS to obtain and study the variations in Stratospheric ozone (Figure 4). Unlike the Tropospheric ozone, the Stratospheric ozone at Kanyakumari is found to decrease during an El Niño period similar to the variations in Total ozone. The trend of Stratospheric ozone at Srinagar and Delhi is found to be opposite to that of Total and Tropospheric ozone. The Stratospheric ozone at these stations is found to be lower during an El Niño period compared to neutral period except in 1985/86. This may indicate a downward transport

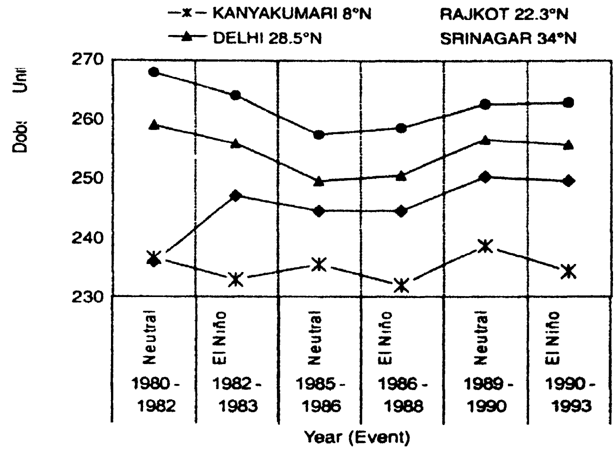

Figure 4. Effect of El Niño on the Stratospheric ozone concentration.

of Stratospheric ozone into the Troposphere at these places, enhanced by Brewer-Dobson circulation during an El Niño period. The low value of observed ozone level in 1985/1986 may be because the neutral years 1985/1986 also correspond to the solar minima years of the 11-year solar cycle, which is associated with an increase in low energy cosmic rays in the Earth's atmosphere, which will increase NOx and in turn, decrease ozone [6]. No significant trend in Stratospheric ozone is observed at Rajkot.

The effect of El Niño on Total ozone was found to be different at these four stations during summer (March-April-May), monsoon (June-July-Aug.), autumn (Sep.-Oct.-Nov.) and winter (Dec.-Jan.-Feb.) (Figures 5–8 respectively). During an El Niño period, the ozone concentration at Srinagar, Delhi and Rajkot was found to be less than that during neutral period by ~10–15 DU in winter (except in 1991/1992 and 2000/2001) and higher than that during neutral period by ~10–25 DU in summer (except in 2000/2001 due to the effect of solar maxima). During monsoon, the ozone concentration is higher during an El Niño period (except in 1989/1990 and 2000/2001 due to the effect of solar maxima). During autumn, the ozone concentration at Srinagar and Delhi is higher during an El Niño period (except in 1987/1988 which corresponds to solar minima) but lower at Rajkot compared to neutral period. At Kanyakumari, the ozone concentration is found to be lower during an El Niño period compared to neutral period during summer as well

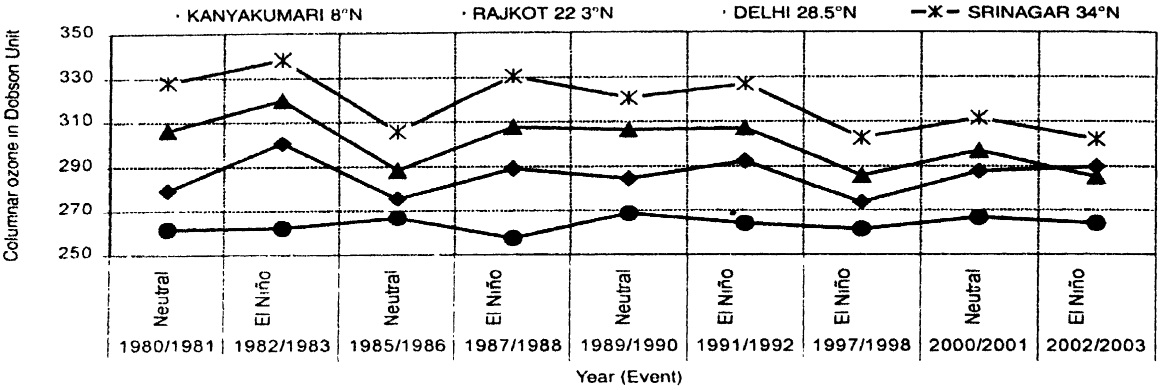

Figure 5. Relation between El Niño and Total ozone during summer.

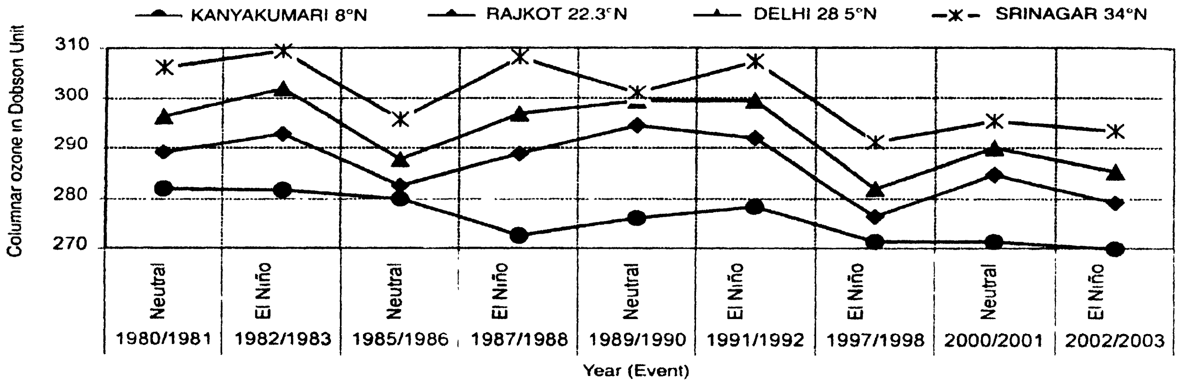

Figure 6. Relation between El Niño and Total ozone during monsoon

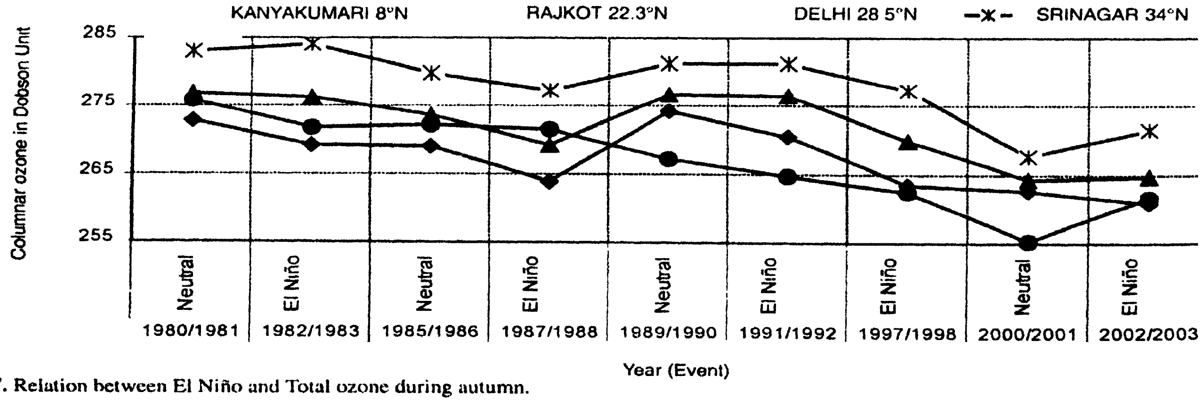

Figure 7. Relation between El Niño and Total ozone during autumn.

as winter (except in 1987/1988) and no significant trend is observed during monsoon and autumn.

The passage of tropospheric weather patterns not only changes the ozone content at the tropopause, but also affects the ozone mixing ratios in the lower Stratosphere. The breakdown in ozone-ENSO relationship at different places in India and the typical behavior of ozone at places like Rajkot located close to the border of Tropics and extra-Tropics may be due to the interference of the annual waves in the two hemispheres, which is further modulated by the Quasi Biennial Oscillation [8]. Moreover, factors like the 11-year solar cycle, volcanic eruptions, long time trend, the seasonal cycle in ozone, consequences of global warming and anthropogenic causes can also be considered

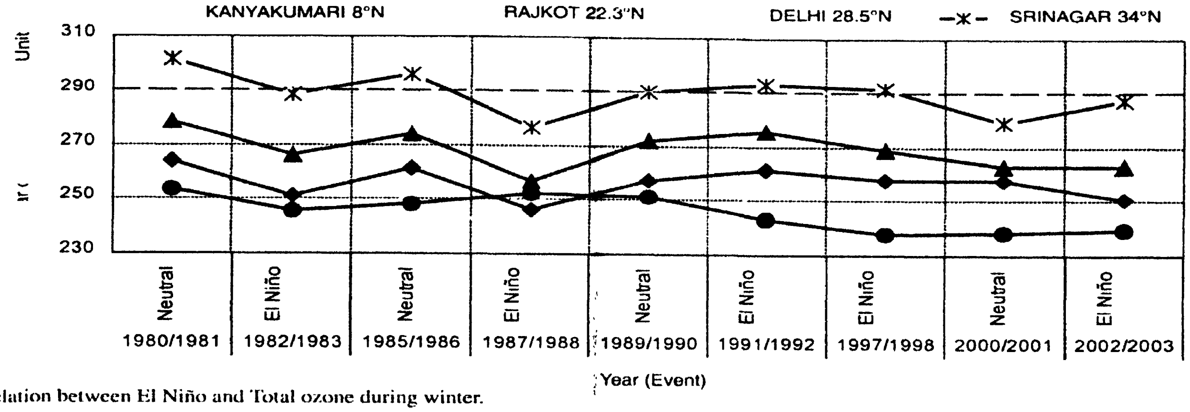

Figure 8. Relation between El Niño and Total ozone during winter.

as sources leading to the breakdown of ozone- ENSO relationship in certain years.

Tropopause plays an important role in the vertical distribution of ozone at a particular place. If the tropopause height decreases, ozone increases and *vice versa*. The Indian atmosphere is mainly dominated by tropical tropopause. Chakrabarty *et al* [9] and Sastry and Narasimhan [10] have observed that the tropopause height is lower in winter than in summer for latitudes higher than 20°N and reverse for latitudes less than 20°N. In an El Niño period, the waters of western Pacific warm up to above normal values. This in turn, causes additional convection (thunder storms) to develop in the western Pacific Ocean, carrying tons of warm moist air upwards into the atmosphere. This warm moisture translates its energy into wind, yielding a stronger sub-tropical jet stream, which then flows eastwards, bringing about a change in the longitudinal structure of tropopause height [11]. According to Gage and Reid [12], tropopause potential temperature and tropopause height are well correlated with southern oscillation index (SOI). Majority of the cut-off lows form during summer months. The tropopause is subjected to significant gaps or breaks which are associated with jet streams [13]. As a result of this break in the tropopause, there is an advection of air and ozone in the troposphere from the extra-tropical latitudes. Whenever this circulation accelerates, the ozone concentration increases in the lower Stratosphere and when it weakens, ozone will decrease or remain constant depending upon its leakage into the Troposphere. During winter, it is possible that deep convection reaching the tropopause warms the upper Troposphere and by overshooting the tropopause, cools the lower Stratosphere and lifts the tropopause. This results in a decrease in ozone concentration. The air temperature measured at Rajkot airport indicates that the temperature is higher during an El Niño period compared to neutral period (Figure 9). The global temperature is also found to be high during an El Niño period (Figure 10). Higher temperature during an El Niño period increases the

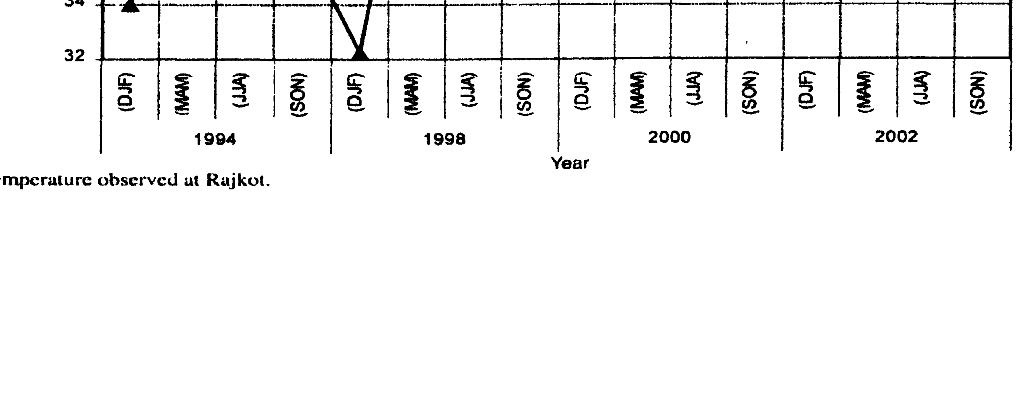

Figure 9. Surface temperature observed at Rajkot.

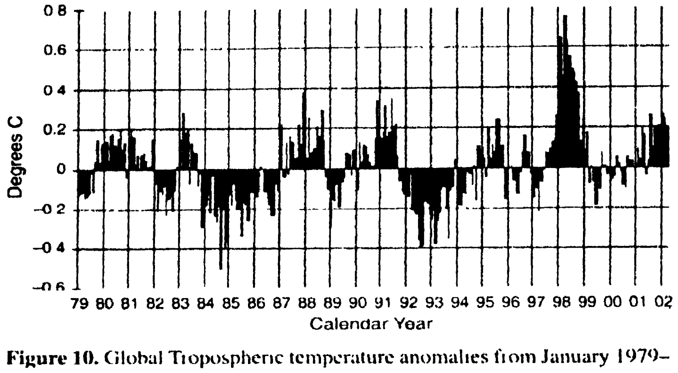

Figure 10. Global Tropospheric temperature anomalies from January 1979–April 2002.

emission rate of ozone precursors [14]. This leads to higher anthropogenic production of surface ozone.

4. Conclusions

The effect of El Niño southern oscillation on the Total, Tropospheric and Stratospheric ozone concentration at Kanyakumari, Rajkot, Delhi and Srinagar is studied using the data obtained from Total Ozone Mapping Spectrometer (TOMS) and Tropospheric Ozone Residual method (TOR). An examination of the yearly mean values of Total ozone from 1980 to 2003 and Tropospheric ozone from 1980 to 1998 indicates that the ozone concentration decreases in the tropics and increases in the extra-tropics during an El Niño period. The Total ozone concentration at Rajkot, which is situated close to the border of tropical and extra-tropical region, is found to be higher during an El Niño period compared to neutral period. No significant trend in Tropospheric ozone is observed at Kanyakumari. The trend of Stratospheric ozone at Srinagar and Delhi is found to be opposite to that of Tropospheric ozone indicating a probable leakage of Stratospheric ozone into the Troposphere during an El Niño period. The effect of El Niño on Total ozone was found to be different at these four stations during summer, monsoon, autumn and winter. During an El Niño period, the ozone concentration at Srinagar and Delhi was found to be less than that during neutral period in winter and higher than that during neutral period in summer, monsoon and autumn. At Kanyakumari, the ozone concentration is found to be lower during an El Niño period compared to neutral period during summer as well as winter and no significant trend is observed during monsoon and autumn. Factors like the 11-year solar cycle, volcanic eruptions, long time trend, consequences of global warming, anthropogenic causes and the seasonal cycle in ozone may be considered as sources leading to the breakdown of ozone-ENSO relationship in certain years at different places in India.

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